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IFPRI Discussion Paper 00912

November 2009

Controlling Cassava Mosaic Virus and Cassava Mealybug in Sub-Saharan Africa

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2020 Vision Initiative

This paper has been prepared for the project on
Millions Fed: Proven Successes in Agricultural Development
(www.ifpri.org/millionsfed)

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IFPRI's research, capacity strengthening, and communications work is made possible by its financial contributors and partners. IFPRI receives its principal funding from governments, private foundations, and international and regional organizations, most of which are members of the Consultative Group on International Agricultural Research (CGIAR). IFPRI gratefully acknowledges the generous unrestricted funding from Australia, Canada, China, Finland, France, Germany, India, Ireland, Italy, Japan, Netherlands, Norway, South Africa, Sweden, Switzerland, United Kingdom, United States, and World Bank.

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Notices

[1] Effective January 2007, the Discussion Paper series within each division and the Director General's Office of IFPRI were merged into one IFPRI–wide Discussion Paper series. The new series begins with number 00689, reflecting the prior publication of 688 discussion papers within the dispersed series. The earlier series are available on IFPRI's website at www.ifpri.org/pubs/otherpubs.htm#dp.

Contents

List of Tables

List of Figures

ABSTRACT

Cassava was imported from Latin America some 300 years ago, and colonial governments in Africa used it as a famine-reserve crop. Over time cassava spread to over 40 countries in Sub-Sahara Africa, and Nigeria is now the largest cassava producer in the world. At Africa's independence in the 1960s, cassava mosaic disease was a major problem. In the 1970s, the cassava mealybug appeared and threatened to decimate the African cassava industry. Cassava mosaic and mealybug control programs were introduced in the 1970s to combat these two problems. The International Institute of Tropical Agriculture (IITA) drew on research on mosaic disease control in Tanzania and developed high-yielding mosaic disease resistant Tropical Manioc Selection (TMS) varieties in only six years of research, from 1971 to 1977. The TMS varieties increased cassava yields by 40 percent without fertilizer. To tackle the mealybug problem, an Africa-wide biological control center was established at the IITA in Nigeria. The IITA brought together an international group of scientists and donors who crisscrossed Central and South America and eventually found a wasp that fed off the mealybug. The wasp was imported from South America into Africa and introduced into cassava fields in over 100 locations throughout Sub-Saharan Africa. The wasp has been effective in bringing the mealybug under control and reduces yield loss by 2.5 tons per hectare. The successful control of both the cassava mosaic disease and the cassava mealybug problems has raised cassava yields and turned cassava into a cash crop that is now spreading throughout Africa. Both cassava success stories are an example of the payoff from problem-solving research that may take many decades.

Keywords: Millions Fed, food security, Cassava, Mosaic Virus, Mealybug, Africa

1. INTRODUCTION

Cassava is commonly known as manioc, yucca, or tapioca. It is a perennial shrub that was introduced from Brazil into West Africa in the sixteenth century and into East Africa in the eighteenth century (Jones 1959). Cassava is grown principally for its swollen roots, though its leaves are also eaten in some parts of Africa. The roots are 25 to 35 percent starch, but the leaves contain a significant amount of protein and other nutrients. About 95 percent of the cassava produced in Africa is used for human consumption and five percent for industrial uses such as starch (Nweke and Haggblade 2009). By contrast, most cassava in Thailand is used for the export of livestock feed or for various industrial uses. In the northeast region of Thailand, cassava led the export take-off, with production rising from 1.7 million metric tons in 1976 to 20.7 million tons in 1996 (World Bank 2009).

The diffusion of cassava can be described as a "self-spreading innovation" in African agriculture. It was initially adopted as a famine-reserve crop because it provided a reliable source of food during drought, locust attack, and during the "hungry season"[1] (Jones 1959). Cassava is currently cultivated in around 40 African countries, covering a wide belt stretching from Madagascar in the southeast to Cape Verde in the northwest.

The cassava mosaic virus disease (hereafter, cassava mosaic disease) was prevalent in East Africa in the 1890s and subsequently spread to most countries in Central and West Africa (Storey and Nichols 1938). On the eve of Africa's independence, Jones (1959) reported that the cassava mosaic disease was the only major disease affecting cassava. In the early 1970s, however, two pests—the cassava mealybug and the cassava green mite—were inadvertently introduced to Africa from South America. The pests spread rapidly and threatened the cassava industry in Africa (Yaninek 1994). In the mid 1980s, cassava mosaic disease was brought under control by the breeding and diffusion of the cassava mosaic disease resistant TMS (Tropical Manioc Selection) varieties. In the late 1970s, biologists launched a search in South America for natural enemies of the mealybug. A small wasp was found to be a parasite that fed on the mealybug; it was multiplied and eventually released in over 100 locations in Africa. The mealybug problem was thus brought under control through a classical biological control program in Sub-Saharan Africa.

This report discusses the cassava mosaic disease and mealybug control programs in Sub-Saharan Africa, drawing mainly on information collected through the Collaborative Study of Cassava in Africa (COSCA). The initial COSCA studies were financed by the Rockefeller Foundation and were carried out from 1989 to 1997 under the aegis of the IITA (International Institute of Tropical Agriculture) in Ibadan, Nigeria. From 1989 to 1992, COSCA researchers collected farm-level data in 281 villages in six countries: the Congo, Cote d'Ivoire, Ghana, Nigeria, Tanzania, and Uganda. From 1993 to 1997, COSCA researchers analyzed the field data and prepared a series of reports on cassava production, processing, and consumption, culminating in publication of *The Cassava Transformation: Africa's Best Kept Secret* (Nweke, Spencer and Lynam 2002).[2]

This report is presented in seven sections. Section 2 presents an overview of the cassava industry in Africa. Section 3 discusses the public and private programs to control cassava mosaic disease. Section 4 discusses the mealybug problem and how it was controlled through a global program. Section 5 discusses the impact of the two control programs. Section 6 discusses the sustainability of the two control programs, and Section 7 summarizes the lessons gleaned from the two control programs.

[1] The period before seasonal food crops are ready for harvest.

[2] Since the original COSCA field studies in the early 1990s, the author has conducted a number of cassava studies in Nigeria and Ghana: a survey of industrial uses of cassava in Nigeria in 2001, financed by the FAO (Food and Agricultural Organization of the United Nations); a survey of government cassava sector development policy in Nigeria and Ghana in 2002, financed by the IFPRI (International Food Policy Research Institute); a survey of traditional West African cassava snack foods in 2003, financed by the IITA; a 15-year follow-up survey of the original COSCA farmers in Nigeria in 2005, financed by the Rockefeller Foundation; and in 2008, a study of the market accessibility for cassava products in Nigeria, financed by the Gates Foundation.

2. CASSAVA IN AFRICA: AN OVERVIEW

Annual cassava production in Africa nearly tripled, from 33 million tons in the early 1960s to 90 million tons in the early 2000s (FAOSTAT). Most of the dramatic increases in cassava production in Africa were achieved in Nigeria and Ghana. In the early 1960s, Nigeria produced only 8 million tons of cassava per year; it was the fourth largest producer in the world after Brazil, Indonesia, and the Congo (FAOSTAT). In the early 2000s, Nigeria produced 32 million tons per year and became the largest producer worldwide, displacing Brazil, Indonesia, and the Congo. Ghana was the seventh largest producer in Africa in the early 1960s, with an annual production of only 1.2 million tons. But in the early 2000s, Ghana produced 8 million tons annually and became the third largest producer in Africa, after Nigeria and the Congo. In Africa, total cassava consumption more than doubled, from 24 million tons per year in the early 1960s to 58 million tons per year in the early 2000s, after accounting for waste (FAOSTAT).

Cassava appeals to low-income rural and urban households because it is the cheapest source of food calories and can be used in an increasing array of food products (for example, g*ari*) as well as for livestock feed and industrial starch. Compared with grain, cassava roots (fresh or dried) are a cheap source of calories. Calories are significantly cheaper from fresh roots of sweet cassava varieties than from maize sold in rural village market centers in Nigeria (Table 1).

Table 1. Nigeria: Retail prices of 1000 calories from fresh cassava roots and maize, 1991

Rural Market Center	Fresh Cassava Roots	Maize
Donga	0.36	0.95
Garbabi	0.38	0.85
Suwabarki	1.09	1.37
Guyuki	0.85	1.60
Namtaringure	0.80	1.20
Yaburawa	0.63	1.11
Wuse	0.81	1.07
Busanfung	0.71	3.20
Ofabe	0.24	0.60

Source: Nweke et al. 2002.

Cassava Myths

Cassava was a subsistence crop in the era when 90 to 95 percent of the people in Africa were in farming. Nevertheless, despite the ability of cassava to produce an acceptable yield under low rainfall conditions, several myths have marginalized cassava in research, policy, and donor circles. The view that cassava is still primarily a subsistence crop is a myth. In Ghana, estimates of the income elasticity of demand for cassava, maize, and rice (based on the World Bank Living Standard Survey data) are revealing: the estimate for cassava was significantly greater among urban households (1.46) than among rural households (0.73). Among the urban households, the estimate for cassava was about the same as the estimate for rice (1.50) and greater than the estimate for maize (0.83) (Alderman 1990).

Another myth is that cassava depletes soil nutrients. In six African countries, the soils of cassava fields were observed to be as fertile as soils of other crops (Nweke and Haggblade 2009). The myth that cassava is a “women’s crop” is an important half-truth; equally important is the other half-truth, that cassava is also a “men’s crop.” Both men and women produce cassava. Men are increasingly involved in cassava production, processing, and marketing as cassava becomes increasingly a cash crop (Nweke and Haggblade 2009). The common stigma that some cassava varieties contain lethal cyanogens is also a half-truth.[3] The cases of cyanide poisoning from cassava consumption are rare, and the fear of it should not discourage public or private investment in the cassava food economy. The cyanogens are eliminated during processing and cassava food preparation by using well-known traditional methods (Nweke et al. 2002).

Many critics claim that cassava is a nutritionally deficient food because of its low protein and vitamin content. However, one does not define beef as a nutritionally deficient food because it has a low carbohydrate and high protein content. Without question, the challenge ahead is to increase the productivity of cassava production, harvesting, and processing in order to drive down the cost of cassava to consumers, especially the poor.

Cassava Production

Cassava is vegetatively propagated with planting sets from stem cuttings. The farmers' most common source of planting sets is their own previous crops, and sometimes purchases in village markets from fellow farmers. COSCA studies revealed that in the early 1990s, less than five per cent of cassava fields were planted with purchased sets, but fifteen years later this increased to around 20 per cent. In the sub-humid savanna zone, planting sets are often in short supply; in the humid forest zone where biomass production is high, there is an abundance of cassava planting sets.[4] But in almost all cases, the planting sets used by the farmers are infected or infested by one or more diseases and pests.

Cassava Weeding

Some scientists report that cassava requires little weeding when planted in optimal plant populations, because the cassava canopy suppresses weeds (Onwueme and Sinha 1991). However, both small- and large-scale farmers consider weeding a major cost because it takes about two to four months for the cassava leaves to close the canopy and suppress weed growth (Dahniya and Jalloh 1998). Commercial producers weed cassava fields twice in the first 12 months and then either harvest it or leave the field to grow into bush along with the cassava.

Harvesting

Cassava does not have a maturity period. It can be harvested as soon as the root is formed. But if it is not harvested, the root continues to enlarge for up to about three years. When the COSCA studies were designed some 20 years ago, it was assumed that the main labor constraints were at the post-harvest stage; however, the high-yielding TMS varieties have shifted labor bottlenecks to the harvesting stage. Cassava harvesting includes chopping off the stem with a machete, pulling up its roots (digging in dry or clay soil condition), and then cutting the roots off the stump. The farmer moves from one plant to another performing these tasks and later gathers the roots to carry them home, to market, or to a processing center. The labor requirement for most of these harvesting tasks increases in direct proportion to yield, because higher yield means larger bulk and weight. The amount of harvesting labor per hectare is especially high in Nigeria because the cassava yields are higher than in the other COSCA study countries (Nweke and Haggblade 2009). Table 2 shows that harvesting cassava is the most labor-intensive field task in Nigeria and Ghana, because TMS varieties have boosted yields by 40 percent.

[3] Cyanogens are poisonous substances.
[4] Purchases were made from local farmers in village markets.

Table 2. COSCA study countries: Cassava production and harvesting labor

Task	Congo	Cote d'Ivoire	Ghana	Nigeria	Tanzania	Uganda
	(person-days per hectare)					
Land Clearing	66	53	44	40	54	45
Seedbed Preparation	21	29	31	41	27	31
Field Planting	39	22	28	32	27	28
Weeding	27	28	34	38	28	32
Harvesting	48	44	53	62	46	52
Total days	201	173	191	222	182	187

Source: COSCA studies.

Common Cassava Foods

In Africa, there are four common groups of cassava foods: fresh root, dried roots, pasty products, and granulated products.[5] Dried cassava root flour is widely prepared and consumed throughout Africa, especially in rural areas (Idowu 1998). There are two broad types of dried cassava roots: fermented and unfermented. Farmers in the savanna zone ferment cassava roots by stacking, while farmers in the forest zone ferment by soaking because of the availability of water. The recent introduction of the grater in processing dried cassava root flour eliminates fermentation and therefore saves time. The roots are simply peeled, washed, grated, pressed to express effluent and cyanogens, and sun dried.

Three forms of pasty cassava products are common in Africa: uncooked, cooked, and steamed pasty cassava products. Pasty cassava products are not as bulky as fresh cassava roots and are therefore less expensive to transport.

Gari is a common type of granulated cassava product. *Gari* is a toasted cereal-like cassava food product that is more common in Nigeria than anywhere else in Africa. It is a convenient product because it is stored and marketed in a ready-to-eat form. It can be soaked in hot or cold water depending on the type of meal being prepared. Since *gari* preparation tasks are labor-intensive, a mechanized method of cassava grating is spreading in Nigeria and Ghana.

Labor Bottlenecks at the Peeling Stage

The processing tasks in the preparation of the three major cassava food products—dried roots, pasty and granulated cassava food products—are time consuming: peeling, for all three products; chipping or grating, for dried roots; crushing and sieving, for pasty products; grating, for granulated products (*gari)*; water expressing, for pasty products, *gari,* and for dried root flour made from fresh roots; sun-drying, in the case of dried roots; toasting, for *gari*; and finally, milling into flour in the case of dried roots. (Dried cassava root flour is made from fresh roots that are grated and then sun-dried.) The processing of pasty products ends with water expressing; *gari* is finished with toasting.

In Nigeria and Ghana, labor-saving mechanical technologies are available for grating, water expressing, and milling. A mechanical grater is used for cassava grating. Mechanized food crop mills are used for converting dried cassava roots into flour, while a mechanical presser is used in several cassava processing centers to express water from grated or crushed soaked cassava mash.

The cassava grating machines are made with locally fabricated components at a cost of $100 to $500 per machine.[6] The machines are usually owned by entrepreneurs who provide services to small-scale farmers for a fee based on quantity. In some villages, the graters are located in the market square; in other villages a grater is mounted on wheels and brought to the fields or homes of farmers who request the services. In many villages, local machine operators in a village processing center provide a

[5] Cassava leaves are an important vegetable in the Congo, Sierra Leone, and Tanzania.
[6] All dollar figures are USD.

comprehensive set of services, including mechanized grating and pressing. In the more comprehensive village processing centers, farmers toast *gari* at the processing center. Maintenance services for the graters are provided by roadside mechanics and welders at any hour of the day. The replacement of hand grating with the mechanized grater has reduced the cost of making *gari* by 50 percent. The COSCA study found that 51 days of labor were needed to prepare a ton of *gari* by hand, and only 24 days were required with a mechanized grater. Peeling is now the most labor-intensive task, followed by the toasting stage in *gari* preparation.

3. CONTROLLING CASSAVA MOSAIC DISEASE

Development of the Mosaic Resistant Varieties

In the 1920s and 1930s, colonial governments initiated cassava research programs in Africa. Experts on colonial agriculture generally agree that the East African Agriculture and Forestry Research Station at Amani in Tanzania (hereafter called the Amani research station) had the most successful colonial cassava breeding program in Africa. The aim of the British-financed Amani research station was to breed cassava varieties that were resistant to the cassava mosaic disease, then spreading rapidly in Africa. The mosaic disease is transmitted by a white fly, *Bemisia tabaci*, as well as by planting cuttings from infected plants; it reduces cassava yields by 30 to 40 percent (Thresh et al. 1997). In 1935, H. H. Storey, a British researcher, conducted a world-wide search for cassava varieties that were resistant to the mosaic disease and developed various disease-resistant rubber species x cassava hybrids. However, these hybrids had low yields, poor food quality, and poor agronomic characteristics such as lodging. During World War II, from 1939 to 1945, the breeding work at the Amani research station in Tanzania was scaled back (Nichols 1947). In 1951, R. F. W. Nichols was replaced as head of the research station by D. L. Jennings, who developed segregates (for example, 5318/34) from the rubber species x cassava hybrids that showed higher resistance than the hybrids created by Storey.[7]

In 1958, at the Moor Plantation research station in Nigeria, B. D. A. Beck crossed the mosaic disease-resistant Ceara rubber x cassava hybrid, 58308, with high-yielding West Africa selections (Jennings 1976). At Nigeria's independence in 1960, the cassava breeding program at Ibadan was moved to the Federal Root Crops Research Institute at Umudike in Eastern Nigeria, and breeding work was continued by M. J. Ekandem. Unfortunately, almost all the progeny developed from the Ceara rubber x cassava hybrid, along with the records of the research, were lost during the Nigerian Civil (Biafran) War (1967-1970). But the original Ceara rubber x cassava hybrid, 58308, was retained at the Moor Plantation research station (Beck 1980).

Cassava breeding at IITA commenced in 1971, when S. K. Hahn was appointed to head the Institute's Root and Tuber Program. Hahn had access to the rich stock of genetic resources that had been developed at the Amani research station in Tanzania, by Storey and others, from the mid 1930s to mid 1950s. Hahn drew on Storey's approach of combining the mosaic-resistance genes of the Ceara rubber x cassava hybrid, 58308, with genes for high yield, good root quality, low cyanogens, and resistance to lodging. After only six years of research (1971 to 1977), Hahn achieved the goal of developing high-yielding mosaic resistant TMS varieties that increased cassava yields on small scale farms by 40 percent without fertilizer. In 1977 the IITA released the following high yielding mosaic resistant varieties: TMS 50395, 63397, 30555, 4(2)1425, and 30572.[8]

Diffusion of the Mosaic Resistant TMS Varieties in Nigeria

The development of TMS varieties resistant to the mosaic virus in Nigeria is an African success story par excellence! No single factor was responsible for this success. The list of contributing factors includes the pioneering work by Storey in the 1930s and 1940s, as well as Hahn's leadership in cassava research at IITA for 23 years. Other contributing factors include the availability of improved cassava processing and food preparation methods. NGOs and the private sector helped distribute the cassava plants.

As Program Director of the Root and Tuber Improvement Program at IITA from 1971 to 1994, Hahn worked to strengthen and expand African agricultural research. He collaborated with National Agricultural Research and Extension Programs and invited donors to support human and physical

[7] In 1956, one year before the Amani research station program was terminated in 1957, Jennings distributed seeds of these segregates to several African countries (Jennings 1976).

[8] The literature on cassava breeding is captured in Evenson 2003a and 2003b and Everson and Gollin 2003.

capacity development at nine of these programs.[9] During his tenure he devoted special attention to training African researchers and extension workers:

- Forty African scientists and extension workers were trained to the M.Sc. and Ph.D. levels.
- Seven hundred technicians attended short-term training courses at IITA.
- Several hundred extension workers were trained through in-country training courses.
- IITA scientists were posted to national research programs to help develop national programs.
- Network activities included regular workshops, frequent exchange visits, and publication of workshop proceedings.
- The Institute provided improved genetic materials in tissue culture forms.[10]

In 1977, when the first TMS varieties were released to farmers, improved methods of cassava food preparation and labor saving mechanical cassava graters were already in place in Nigeria. Farmers' access to mechanical graters reduced the cost of preparing cassava as *gari*, increased the profitability of planting the TMS varieties, and released labor—especially female labor—for planting more cassava (Camara 2000).

The physical presence of the IITA in Nigeria was influential in eliciting help from non-governmental organizations in the diffusion of the TMS varieties. For example, from 1988 to 1991, multinational oil companies in Nigeria multiplied and supplied TMS planting sets to a large number of farmers, cooperative societies, women's associations, churches, and schools.[11]

With the aid of petroleum revenue, the Nigerian government experimented with alternative extension programs and expanded higher education and agricultural research institutions in the 1970s and 1980s. The adoption of the TMS varieties was promoted by Nigeria's national extension program under the NAFPP (National Accelerated Food Production Program) and the ADPs (Agricultural Development Projects). In 1986, the Federal Government of Nigeria helped secure a $120 million grant from the IFAD (International Fund for Agricultural Development) and directed the National Seed Service to assist the ADPs in the multiplication of the TMS varieties. The National Seed Service (NSS) multiplied and distributed free stem cuttings of the TMS varieties to farmers. In 1989 COSCA researchers found that farmers in 60 percent of the surveyed villages in Nigeria had planted the TMS varieties (Nweke and Haggblade 2009). Fifteen years later, the TMS varieties were grown in all of the COSCA-surveyed villages in Nigeria.

Delayed Diffusion of the Mosaic Resistant TMS Varieties in Ghana and Uganda

Until the early 1980s, Ghana's food policy favored cereals—maize and rice, the long time favorites. Widely-believed myths about cassava discouraged the government from investing in measures to diffuse the TMS varieties to farmers, until its interest in the mosaic-resistant cassava varieties was awakened by a severe drought in 1982 and 1983. Cassava survived the drought and helped people cope with food insecurity (Korang-Amoakoh 1987).

In 1984, Ghana's Commissioner for Agriculture visited the IITA in Ibadan and met with Hahn. During their discussion, the Commissioner described the roles of maize and cassava in food policy in Ghana using the expression, "Monkey de work, Baboon de chop." His meaning was: cassava is feeding

[9] The National Programs involved were: Zaire National Cassava Program (PRONAM), Nigeria National Root Crop Research Institute, Cameroon National Root and Tuber Improvement Program, Ghana National Root and Tuber Improvement Program, Rwanda National Root and Tuber Improvement Program, Uganda National Root and Tuber Improvement Program, and Malawi National Root and Tuber Improvement Program. The donors who supported the national programs were USAID, IDRC (Canada), AGCD (Belgium), Gatsby Foundation (UK), IFAD, World Bank, UNICEF, and UNDP.

[10] Hahn, S. K. 2009. Personal communication, July 2, 2009.

[11] Hahn, S. K. 2009. Personal communication, July 2, 2009.

the people, but maize is consuming research resources. In 1985, Ghana hosted the Central and Western African Root Crops Network workshop in Accra. The workshop helped government officials grasp the importance of cassava in Ghana (Obimpeh 1994). In 1988, eleven years after the TMS varieties were released in Nigeria, the Government of Ghana imported the TMS varieties from IITA and turned them over to Ghanaian researchers for field testing. Hahn helped the government of Ghana obtain IFAD funding for on-farm testing of the TMS varieties from 1988 to 1992.

In 1993, sixteen years after the release of the TMS varieties in Nigeria, the Government of Ghana released three TMS varieties to farmers. In February 2001, cassava scientists at the Crops Research Institute in Kumasi reported that the TMS varieties were widely grown by farmers in the Eastern, Greater Accra, and Volta regions, where farmers prepare *gari* for sale in urban centers. The 16-year delay in Ghana illustrates the need for political leadership in promoting the adoption of new technology from neighboring countries.

In Uganda, government interest in the mosaic-resistant TMS cassava varieties was aroused in 1988 by the appearance of an unknown but severe form of the cassava mosaic disease (Ssemakula 1997). This disease has since been designated as the Uganda variant (UgV) of the East Africa cassava mosaic disease. Surveys to monitor the progress of the UgV epidemic revealed that the epidemic spread southwards along a broad “front” at a rate of approximately 20 km per year. The front was marked by a large number of whiteflies and by a high incidence of recent infection due to whitefly transmission.

To address this problem, Ugandan scientists in the Root Crops Program of NARO (National Agriculture Research Organization) introduced the mosaic-resistant TMS varieties obtained from the IITA (Otim-Nape and Buea 2000). In 1994, following on-farm tests, three varieties (TMS30572, TMS60142, and TMS30337) were released to farmers (Ssemakula 1997). Multiplication and distribution of the planting sets of the mosaic-resistant TMS varieties were undertaken by NARO, with financial and technical support from several organizations.[12] NARO created NANEC (National Network of Cassava Workers) to distribute the planting sets to farmers because, it believed, existing institutions such as the Extension Service of the Ministry of Agriculture were inadequate to implement the distribution. NANEC established branches in all cassava-growing districts and brought together cassava stakeholders at the district level—including contact farmers, the district agents of the Extension Service of the Ministry of Agriculture and NARO, political leaders, and others—and through them distributed the planting sets to farmers.

The University of Greenwich (2000) reported that the area planted to the mosaic-resistant TMS varieties in Uganda increased from 20 percent of the total cassava area in 1993 to 60 percent in 1996 and 80 percent in 1998. Studies of the presence of the UgV of the mosaic disease revealed that the incidence of the disease declined from over 90 percent on the mosaic-susceptible local varieties to less than 20 percent on the mosaic-resistant TMS varieties. Moreover, the severity of the disease was high on the local varieties but mild on the TMS varieties, with hardly any reduction of root yield (University of Greenwich 2000).

Performance of the TMS Varieties in Nigeria

The TMS breeding efforts of the IITA team were aimed at developing resistance to the cassava mosaic disease. But in order to achieve their full yield potential, the TMS varieties must also be resistant to, or at least tolerant of, other important cassava diseases and pests, notably the cassava bacterial blight, cassava mealybug, and cassava green mite. The TMS varieties must also address other needs of farmers: early harvesting; ability to suppress weeds and suitability for intercropping; ease of harvesting and peeling; low cyanogen content; and suitability for making various food products.

In Nigeria, the TMS varieties were more resistant than local varieties not only to the mosaic virus but also to bacterial blight, the mealybug, and the green mite (Table 3). The farm-level yield of the TMS

[12] The IITA, the NRI (Natural Resources Institute), IDRC (International Development Research Center), the Gatsby Charitable Foundation, and USAID (United States Agency for International Development).

varieties, when grown without fertilizer, was 40 percent higher than local varieties (19 tons compared to 13.6 tons per hectare).

Table 3. Nigeria: Incidences and symptom severity scores (1-4 scale) of cassava problems by local and TMS varieties.

Problem		Local varieties (N=93)	TMS varieties (N=49)	t-ratio*
Mealybug	Percentage infested	50	20	--
	Mean severity	2.0	1.2	3.15
Green mite	Percentage infested	26	4	--
	Mean severity	1.5	1.0	3.68
Mosaic disease	Percentage infected	62	73	--
	Mean score	1.9	1,5	2.45
Bacteria blight	Percentage infected	63	71	--
	Mean score	1.9	1.3	4.20

Source: Nweke et al. 2002.

Note: P<0.001 in all cases.

The TMS varieties attain their peak yield around 13 to 15 months after planting, as compared to 22 to 24 months for local varieties. Nevertheless, Nigerian farmers who produce cassava under increasing demographic and market pressures desire varieties that can be harvested in less than 12 months, in order to be able to prepare the fields for double-cropping.

TMS varieties are mostly branching types with large canopies that are good for weed control. But in spite of the large canopy, COSCA studies have found no significant difference between the TMS varieties and the local varieties in terms of intercropping. For example, 50 percent of the area of the TMS varieties and 55 percent of area planted to the local varieties in Nigeria were intercropped with yam, maize, and other crops.

Nigerian farmers complained that harvesting the high-yielding TMS varieties by hand was laborious. Farmers in Southwestern Nigeria, who planted the TMS 30572 to produce *gari* for sale in Lagos, reported that they had to cut back drastically on the area planted to cassava because they lacked enough seasonal labor to harvest and process the crop of the previous season in a timely fashion.

The Nigerian farmers who produced cassava as a cash crop and made *gari* for sale to urban consumers praised the TMS varieties as being ideal for *gari* production. However, they complained that peeling the TMS varieties is laborious and results in substantial waste, because the roots can only be peeled by slashing the skin and part of the root-flesh with a sharp knife. Mechanized machines have not been developed for cassava peeling because cassava roots vary in size and shape: farm-level yield measurements show that the roots of the TMS varieties ranged in size from 0.10 kg to 1.14 kg. There is a need for breeders to develop cassava varieties which produce roots with uniform shape and size, and for engineers to develop mechanized peeling machines.

The roots of the TMS varieties are lower in cyanogen content than those of local varieties (an average of 2.20 on a one-to-three scale, compared to 2.35). Sweet cassava occupied roughly 30 percent and bitter cassava about 70 percent of the area planted with the TMS varieties, the same proportion as the local varieties.[13]

[13] Cassava varieties which farmers can eat without processing are called sweet; those that must be processed before eating are called bitter.

4. THE CASSAVA MEALYBUG CONTROL PROGRAM

The cassava mealybug was accidentally introduced in the Congo in the early 1970s in infested planting materials from South America. The mealybug spread throughout the cassava belt of Africa, sharply reducing cassava yields. In just ten years, the cassava mealybug threatened to wipe out cassava in Africa (Herren 1981, Norgaard 1988).[14] The pest was spread by the wind as well as through the exchange of infested planting materials. The mealybug feeds on the cassava stem, petiole, and leaf near the growing point of the cassava plant. During feeding, the mealybug injects a toxin that causes leaf curling, slowing of shoot growth, and eventual leaf withering. Yield loss in infested plants is estimated to be up to 60 percent of root and 100 percent of the leaves[15] (Herren 1981).

Establishment of the Africa-Wide Biological Control Program

The growing concerns of farmers, scientists, agricultural policy makers, and political leaders over the cassava losses from mealybugs were discussed at an international conference in the Democratic Republic of Congo in 1973. One of the recommendations of the conference was that biological control and resistance breeding should be undertaken by the IITA and other institutions (Alene et al. 2005).

Researchers and policy makers reviewed the options and decided that the classical biological control solution—the reuniting of predators with their previously dislocated prey—was the best approach to pursue. Few chemicals are used by smallholders in Africa, and the process of resistance breeding was considered too slow to address the emergency problem (Hahn et al. 1981). Following requests from numerous African countries, a regional approach was adopted in 1980. The ABCP (Africa-wide Biological Control Program) of cassava pests was established at IITA in Nigeria, with three objectives: to achieve permanent, ecologically safe and economically sustainable control of the cassava mealybug and the cassava green mite throughout the African cassava belt; to provide specialized training in biological control techniques; and to initiate national biological control programs.

International Collaboration

In an undertaking of this size, no single institution had the capacity to handle all the essential aspects: foreign exploration, quarantine, rearing, release, field and laboratory studies, monitoring, coordination, training, awareness creation, and impact studies. IITA therefore organized a network of collaborators in Africa, Europe, and North, Central, and South America as part of the implementation of the ABCP (Wodageneh and Herren 1987). The IAPSC (Inter-African Phytosanitary Council) of the African Union provided regulatory and regional liaison services from the beginning of the cassava mealybug project. IITA coordinated collaboration with CIAT (Centro Internacional de Agricultura Tropical) in Colombia, CIBC in London, and the Nigerian quarantine service. Agreement from quarantine facilities all over Africa was obtained to import beneficial insects into their respective countries.

Foreign Exploration, Quarantine and Importation

Since both cassava and the cassava mealybug evolved together in South America, the ABCP scientists looked to that continent for a solution to the mealybug epidemic in Africa. Starting in the late 1970s, a systematic search for the cassava mealybug and its potential natural enemies was undertaken in much of Central and South America and from southern California to Paraguay. Although huge areas of South America were scanned, mealybug was found only in a very restricted area of the continent. ABCP scientists found a natural enemy, a parasitic wasp called *Anagyrus (Apoanagyrus, Epidinocarsis) lopezi* (hereafter, *A. lopezi*), which uses the mealybug as the site for laying its eggs and whose developing larvae then kill the mealybug (Herren et al. 1987; Herren and Neuenschwander 1991; Neuenschwander 2001).

[14] See Neuenschwander (2001) for an excellent review article on the mealybug program.
[15] Cassava leaf is consumed as a vegetable in some African countries.

All the natural enemies of the cassava mealybug destined for introduction in Africa were sent for quarantine to the IIBC (International Institute of Biological Control) at CABI in Silwood Park, England. To ensure that the insects would not become a problem in their new environment, they were reared through one generation and tested for harmlessness to bees and silkworms, absence of pathogens, and relative specificity. This last criterion guarded against the introduction of general natural enemies that could endanger indigenous plants and animals. For the ABCP of the cassava mealybug, it was particularly aimed at exclusion of hyperparasitoids, in order to establish in Africa the natural balance that existed in South America. From quarantine, primary parasitoids and oligophagous predators were sent to IITA, first in Nigeria and then in Benin, for further study, mass-rearing, and finally release.[16]

Rearing and Releasing Biological Control Agents

Mass rearing and distribution techniques were developed for the introduced biological control agents at IITA, Ibadan, Nigeria. Producing and delivering the biological control agents was a challenge because of the huge size of the project. The timing of operations was also influenced by administrative decisions in various countries, leading to unpredictable requests for the biological control agents. To satisfy the high and shifting demand for the biological control agents, simplified rearing techniques were developed by local scientists (Neuenschwander and Haug 1992). To test their capability to establish in the new environment, several different biological control agents that had successfully passed quarantine were released at experimental sites: *A. lopezi, H. notata, D. Hennessey, Hyperaspis* sp., *Allotropa* sp., *A. diversicornis, H. jucunda,* and *S. maculipennis*. Releases were made on the ground by pouring the biological control agents onto infested cassava plants. Because ground release was not possible in several locations owing to poor road infrastructure, aerial release techniques were developed at the IITA and adopted for such locations (Herren et al. 1987 and Neuenschwander and Haug 1992). From 1981 to 1994, releases were made in 120 sites in about 30 African countries. The releases were all done in collaboration with colleagues from the national research programs. At the release sites, the establishment and the spread of the biological control agents were monitored through samplings of mealybug. *A. lopezi* (the wasp) quickly became the dominant species among all the introduced biological control agents.

Performance of Biological Control Program

The various biological control agents were monitored to determine their performance in cassava mealybug control and their effect on non-target species in the fields where they were released. Field experiments demonstrated that *A. lopezi's* host-finding and aggregation capacity surpassed that of all the other control agents. The effectiveness of *A. lopezi* in controlling the cassava mealybug populations was evaluated using exclusion experiments, long-term population dynamics studies, laboratory and field experiments, and large-scale surveys (Neuenschwander 1996). Physical and chemical exclusion experiments demonstrated the effectiveness of *A. lopezi* in southwestern Nigeria. Under rainforest conditions in Ghana, when cassava mealybug was protected from *A. lopez* their populations were much higher. More importantly, seven years of continuous monitoring in numerous fields in two areas of southwestern Nigeria revealed that the mean cassava mealybug population never reached the height or the duration observed during the first season of release. A survey covering the whole of Nigeria revealed cassava mealybug infestation levels of below 10 mealybugs/tip, with only 3.2 percent of all tips being stunted (Neuenschwander and Haug 1992). The mealybug population reduction remained stable, with small peaks at about 10 percent of outbreak levels (Alene et al. 2005).

In a large-scale survey across different ecological zones in Ghana, yield loss due to cassava mealybug was reduced significantly (Neuenschwander et al. 1989). The presence of *A. lopezi* translated into a reduction in yield loss of 2.5 tons per hectare. The performance assessment was based on surveys using a regular, nonbiased choice of fields and random samples within each field (Schulthess et al. 1989).

[16] Oligophagous predators are insects that feed on a restricted range of food substances, especially a limited number of plants or other insects.

The field studies revealed that the introduction of *A. lopezi* led to some competitive displacement, but not to the extermination of indigenous parasitoids or predators. The introduced organisms were found to fulfill modern safety requirements (Neuenschwander 2001).

5. IMPACT OF THE CASSAVA MOSAIC AND CASSAVA MEALYBUG CONTROL PROGRAMS

The research culminating in the development and release of the mosaic-resistant high-yielding TMS varieties in Nigeria was achieved with an annual budget ranging from $500,000 to $4.6 million from 1971 to 1977. The annual economic rate of return from that investment was 55 percent, throughout a 31-year period (Maredia, Byerlee and Pee 2000).

Neuenschwander and Haug (1992) reported that, from inception to the end of 1988, the total cost of the cassava mealybug biological control project in Africa was equivalent to $10.00 per hectare of cassava, as a one-time expense to reduce the cassava mealybug for subsequent years. The benefit-cost ratio estimates of this biological control program (estimated by different researchers over different periods, using widely different assumptions) range from 94:1 to 800:1. For example, Norgaard's landmark study (1988), using a 24-year time frame, estimated the benefit-cost ratio for the mealybug control program at 149 to 1.[17] A research team headed by Zeddies et al. (2001), using a 40-year time frame, concluded that the benefit-cost ratio was about 200:1 when cassava was costed at world market prices and ranged from 370:1 to 740:1 at inter-African prices. These findings demonstrate that biological control can play an important role in pest management.

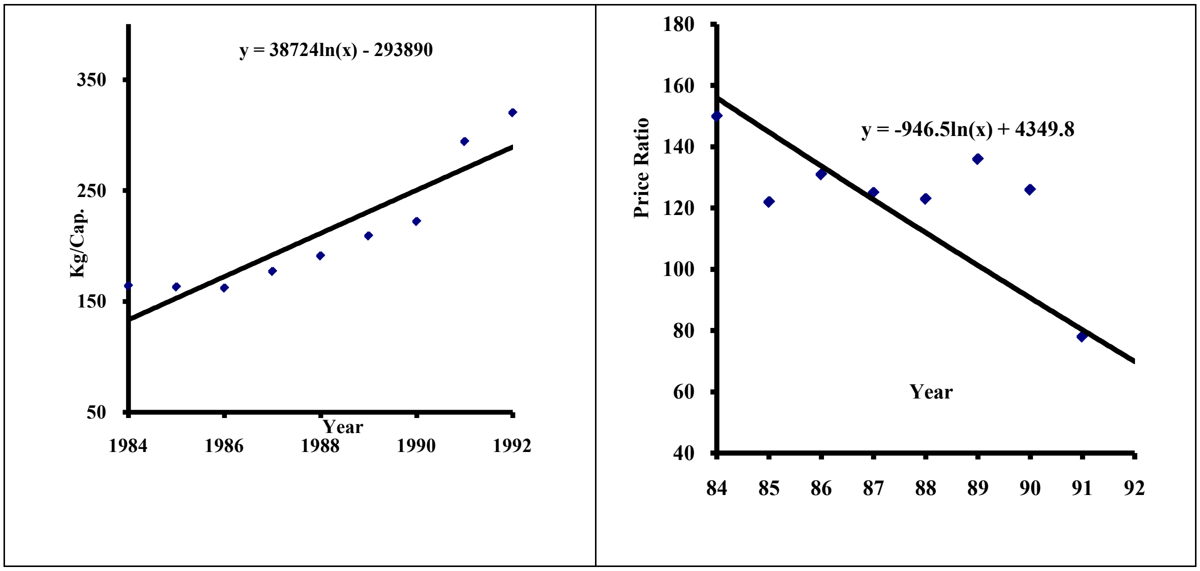
But impact estimates based on internal rates of return and benefit-cost ratios are limited by their assumptions, especially in Africa where farm-level data are scarce and unreliable (Nweke 2005). For example, the estimate of internal rate of return did not take into account the TMS diffusion costs in Nigeria, including the multiplication and free distribution of planting sets to farmers. Nor do these estimates consider the value of the TMS varieties accruing to other countries, such as Ghana and Uganda, which are now importing, testing, releasing, and diffusing the varieties to farmers. It is not clear, moreover, how the internal rate of return takes account of the possibility that the TMS mosaic-resistant varieties might break down within the estimation period. Likewise, the benefit-cost estimate of the mealybug control program did not account for ecological and health benefits—nor the potential benefits to other cassava-producing regions threatened by the mealybug.

Impact on Production and Consumer Prices

Nigeria is an ideal country for studying the impact of these control programs on cassava production and consumer prices. The TMS cassava varieties were first released to farmers in Nigeria in 1977, followed by a large diffusion program starting in the mid-1980s. During the release of the biological control agents and rapid diffusion of TMS varieties from the mid-1980s to the early 1990s, Nigeria's per capita cassava production increased (Figure 1a). The IITA, drawing on data from the COSCA study, calculated that the TMS varieties contributed an extra 1.4 million tons of *gari* per year than would have been available from local varieties—an amount sufficient to feed 29 million people (CGIAR 1996). By the end of the 1980s, cassava prices fell sharply, as reflected in the *gari*-to-yam price ratio (Figure 1b). The average inflation-adjusted *gari* price from 1984 to 1992 (18,000 Naira per ton) was 40 percent lower than the price prevailing in the prior period, from 1971 to 1983 (29,000 Naira per ton)—before the TMS diffusion and before the mealybug was brought under control. This dramatic reduction in *gari* prices represents a significant increase in the real income of the millions of the poor rural and urban households who consume cassava as their staple food. The major economic benefit from the control of the cassava mosaic disease and cassava mealybug accrued to consumers (Afolami and Falusi 1999).

[17] Norgaard only had access to West African data, and he extrapolated these data for the whole continent.

Figure 1. Nigeria: Per capita cassava production and g*ari* to yam price ratio, 1984–1992.



a. Cassava production   b. *Gari* to yam price ratio

Source: Nweke and Haggblade 2009.

In Nigeria, cassava production is a major source of calories and cash income for farm households. The COSCA studies in 1992 revealed that food crops contributed 55 percent of cash income for study households. Cassava, the most important single cash income source, accounted for 12 percent of the total cash income per farm household, compared to 8 percent for yam and maize respectively, and only 6 percent for rice.

These two programs also improved the income position of small producers relative to the large producers (Afolami and Falusi 1999; Johnson et al. 2006). Cassava sales proved more egalitarian than the alternative staples, such as yams and maize: cassava cash income accrued to more households than did earnings from other major staples. Among rural households, 40 percent earned cash income from selling cassava, while 35 percent earned cash from selling maize and 24 percent earned income from selling yams. Although food sales typically remain highly concentrated among an upper stratum of smallholder farmers, cassava sales accrue to a broader spectrum of farm households than do other food staples. The top 10 percent of cash-earning households from the COSCA villages earned 50 percent of all cassava cash income—but they also garnered 60 percent of yam earnings and 70 percent of maize sales.

6. SUSTAINABILITY OF CASSAVA MOSAIC AND MEALYBUG CONTROL

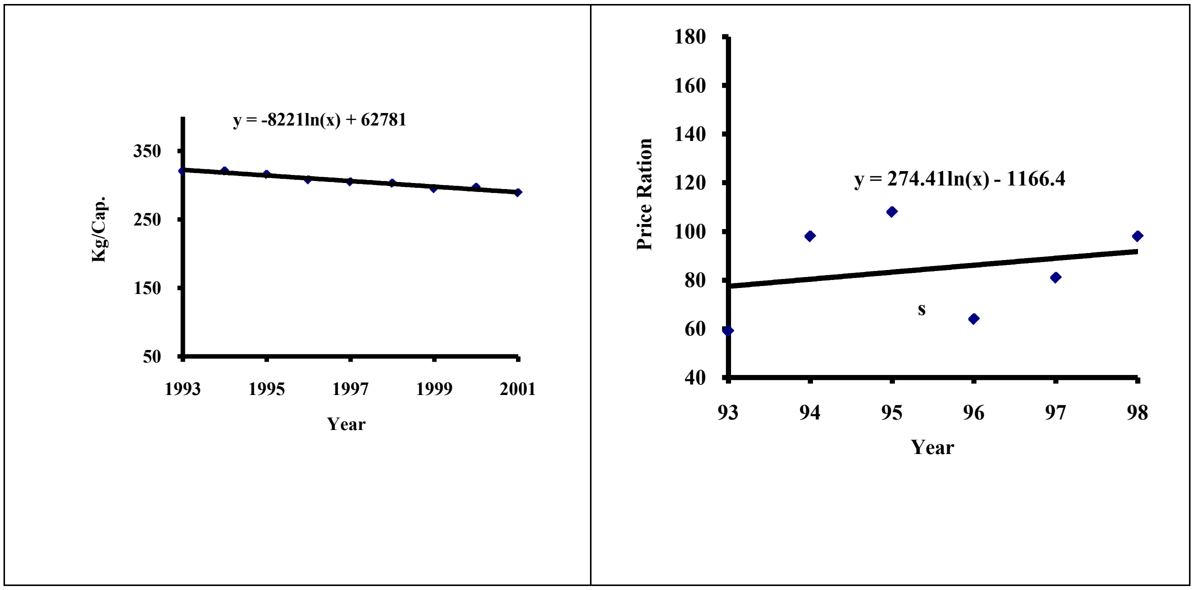
In discussing the sustainability of the mosaic disease control program, two issues arise: sustaining the mosaic resistance *quality* in the TMS varieties; and sustaining the *planting* of TMS varieties by farmers. In crop breeding, disease resistance tends to decline with each generation of seed that is saved and replanted. Therefore, farmers need to collect new seeds either from research institutes or from specialized seed companies each season to continue to realize the benefits of the new varieties. In Nigeria, however, the TMS multiplication and free distribution program assumed that farmers did not need to collect new stem cuttings (planting sets) each season in order to continue to sustain the mosaic resistance quality of the TMS varieties.

In 2003, the IITA conducted a diagnostic survey of cassava in Nigeria to determine the status of the cassava mosaic disease in the country (Ogbe et al. 2004). The results showed that the cassava mosaic disease was significantly reduced among the TMS varieties compared to local varieties. In 1989, the COSCA studies produced a similar result, conducted by the same NRCRI (National Root Crops Research Institute Stations) scientists. Even in the absence of a renewed supply of planting sets (by a research organization or specialized seed company), the TMS varieties sustained their superiority over local varieties in mosaic disease resistance over nearly 15 years, from 1989 to 2003.

The expansion of the planting of the mosaic-resistant varieties by farmers depends on addressing two second-generation problems with the TMS varieties: high harvesting and peeling labor costs, and declining cassava prices as a result of increased production. Both of these problems are due to the high yield achieved with the TMS varieties. Farmers who face increasing costs and declining prices are likely to reduce the size of their cassava planting. Evenson and Gollin (2003) report that, where productivity rose more than prices declined, farm families gained from the Green Revolution in Asia and South America. In the case of the high-yielding mosaic disease-resistant TMS cassava varieties, however, cassava prices declined faster than the farm wage rate. For example, in Nigeria over a ten-year period, the farm wage rate in real terms nearly tripled, from the equivalent of $1.25 per man day in 1991 to $3.50 in 2001 (an increase of 180 percent). In comparison, the price of *gari* increased from an equivalent of $185 per ton in 1991 to $255 per ton in 2001—less than a 40 percent increase. Labor is the main cost of cassava production in Nigeria. Under these conditions, progressive farmers who plant the high-yielding TMS varieties in Nigeria have sometimes suspended planting because they were unable to hire sufficient labor to harvest previously planted cassava fields (Nweke and Haggblade 2009).

The result is that, from the early 1990s to the early 2000s—after the period of rapid diffusion of TMS varieties in Nigeria—cassava production per capita *declined* and cassava prices to consumers increased (Figure 2). Progressive farmers who were planting the high-yielding mosaic disease-resistant TMS varieties were planting less cassava because they faced serious labor bottlenecks at the harvesting, peeling, and processing stages, with labor requirements that increase in direct proportion to yield.

Figure 2. Nigeria: Per capita cassava production and g*ari* to yam price ratio, 1993–2001.



a. Cassava production b. *Gari* to yam price ratio

Source: Nweke and Haggblade 2009.

The high yield obtained with the mosaic disease-resistant TMS varieties has shifted the cassava labor bottleneck from weeding to harvesting and peeling. Farmers who produce cassava as a famine reserve crop or as a rural food staple do not consider cassava harvesting a labor-intensive task, as they harvest cassava piecemeal. But farmers who produce cassava as a cash crop for urban markets groan under the burden of high cassava harvesting labor costs. Harvesting is now proving to be a serious constraint on the planting of mosaic disease-resistant TMS varieties, as labor requirements for cassava harvesting increase in direct proportion to yield.

The Mealybug Control

The cassava mealybug control program using biological control agents was a self-spreading innovation that only needed a modest diffusion effort. The biological control agents required no initial investment, whether by farmers, credit programs, or extension services. No manufacturing or distribution system was needed because the biological control agents reproduced and dispersed themselves following their release in the cassava fields (Norgaard 1988). Without question, the biological control of the cassava mealybug with the aid of the biological control agents is one of the important scientific success stories in African history. The speed of dispersal of *A. lopezi* after release was high, between 50 km and 100 km per year. Two years after the release, *A. lopezi* was observed in a wide area beyond each original release site (Neuenschwander and Haug 1992). There is no reason to expect that the *A. lopezi* will one day disappear from cassava fields, unless there are no mealybugs to feed on. Neuenschwander (2001) reported that the much dreaded “resurgence” (understood here as a permanent increase in host populations following successful biological control) has not been observed, and it is not likely to occur with the cassava mealybug.

7. LESSONS LEARNED

Five lessons flow from this analysis of two highly successful programs in Sub-Saharan Africa—the control of cassava mosaic disease and control of the cassava mealybug. Both provide insights for tackling Africa's food production and poverty problems. Five factors played a role in these success stories.

1. *Research: the driving force.* Both of these control programs add evidence that research is the driving force of cassava production programs in Sub-Saharan Africa. Both success stories highlight the role that research played in expanding food production and thus helping to reduce food prices and rural and urban poverty. This analysis documents how the rapid adoption of cassava varieties with improved resistance to cassava mosaic disease led to dramatic increases in cassava production in the 1980s and 1990s, in Nigeria, Ghana, and Uganda. The expansion of cassava has been sparked by demand-side shifts to food products such as *gari* and *fufu*. But Africa still has much to learn about the critical role of research; for example, research in Thailand sparked the export of cassava pellets for livestock feed to the European Union. Thailand's research also includes the development of shorter season varieties, thus opening the door for double-cropping.
2. *Global approach.* Without question, cassava is Africa's most significant "global commodity." It was brought to Africa some 300 years ago from Latin America and is rapidly replacing maize as Africa's most important food crop. The research base for controlling cassava mosaic stems from colonial research at the Amani research station in Tanzania in the l930s and 1940s. Thirty years later, IITA's research on cassava mosaic virus drew on the Amani research findings and developed the high-yielding mosaic-resistant TMS varieties that increased cassava yield by 40 percent without fertilizer. To tackle the mealybug problem, an Africa-wide biological control center was established at the IITA in Nigeria. The IITA brought together an international group of scientists and donors, who crisscrossed Central and South America and eventually found a wasp that fed off the mealybug. The use of the wasp to control the cassava mealybug reduced yield loss by 2.5 tons per hectare. Both the cassava mosaic and the mealybug control programs demonstrate how global partnerships can capture the synergies of local, regional, Pan African, and global cooperation.
3. *Time and continuity of investigation.* Both the cassava mosaic and mealybug control programs represent a classic case of the incremental benefits of research—in this case, borrowing cassava technology from the global research community. The leader of the IITA's roots and tuber programs carried out a cassava research program for 23 years, providing an extended opportunity to train hundreds of cassava specialists in graduate degree programs and in short-term training programs at IITA as well as in "tailor-made" in-country programs. The continuity of scientific leadership is also important in pinpointing and addressing second-generation problems, such as the harvesting labor bottleneck that arose from planting high-yielding mosaic-resistant TMS varieties.
4. *Transformation of cassava as a cash crop for sale in rural and urban markets.* For generations, cassava has been conceived and promoted as a famine-reserve crop in Africa. The most unexpected finding of this study is the surge in demand for cassava as a *cash crop*, reflecting the sharp decline in the price of cassava relative to maize and other food staples. Cassava is now an important cash crop in Africa. This transformation is being propelled by the control of the cassava mosaic virus and mealybug problems.
5. *Sustainability.* This study shows that both mosaic and mealybug control programs have been successful and they reinforce each other. The achievements of both control programs in contributing to high yield of cassava have been sustained for a period of about 25 years. It remains to be seen how much longer the high yields can be sustained. One thing is clear:

research on the mosaic and mealybug controls needs to be continued in order protect and sustain the substantial achievements that have been attained.

REFERENCES

Afolami, C. A., and A. O. Falusi. 1999. Effect of technology change and commercialization on income equity in Nigeria: The case of improved cassava. Paper presented at the "International Workshop on Assessing the Impact of Agricultural Research on Poverty Alleviation," September 14–16, San Jose, Costa Rica.

Alderman, H. 1990. Nutritional status in Ghana and its determinants. In *Social dimensions of adjustment in Sub-Saharan Africa*, Policy Analysis Working paper No. 3. Washington, D.C.: World Bank.

Alene, A., D. Arega, P. Neuenschwander, V. M. Manyong, O. Coulibaly, and R. Hanna. 2005. The impact of IITA-led biological control of major pests in Sub-Saharan African agriculture: A synthesis of milestones and empirical results. Impact Series. Ibadan, Nigeria: IITA.

Beck, B. D. A. 1980. Historical perspectives of cassava breeding in Africa. In *Root crops in Eastern Africa*, Proceedings of a workshop held in Kigali, Rwanda, November 23–27. Ottawa: International Development Research Center.

Camara, Y. 2000. Profitability of cassava production systems in West Africa: A comparative analysis (Cöte d'Ivoire, Ghana, and Nigeria). PhD dissertation, Michigan State University, East Lansing.

CGIAR (Consultative Group on International Agricultural Research). 1996. *Report of the fourth external program and management review of the IITA*. Rome: TAC, FAO.

Dahniya, M. T., and A. Jalloh. 1998. Relative effectiveness of sweet potato, melon, and pumpkin as live-mulch in cassava. In *Root crops and poverty alleviation,* ed. M. O. Akoroda and I. J. Ekanayake. Proceedings of the Sixth Triennial Symposium of the International Society for Tropical Root Crops—African Branch (ISTRC–AB), Lilongwe, Malawi, October 22–28, 1995. Ibadan, Nigeria: International Institute of Tropical Agriculture.

Dalton, T., N. Lilja, N. Johnson, and R. Howeler. 2007. CIAT. Impact of participatory natural resource management research in cassava-based cropping systems in Vietnam and Thailand. In *The impact of natural resource management research: Studies from the CGIAR,* ed. H. Waibel and D. Zilberman. Wallingford, U.K.: CAB International.

Evenson, R. E. 2003a. Modern variety production: A synthesis. In *Crop variety improvement and its effect on productivity: The impact of international agricultural research,* ed. R. E. Evenson and D. Gollin. Wallingford, U.K.: CABI Publishing.

________. 2003b. Production impacts of crop genetic improvement. In *Crop variety improvement and its effect on productivity: The impact of international agricultural research,* ed. R. E. Evenson and D, Gollin. Wallingford, U.K.: CABI Publishing.

Evenson, R. E., and D. Gollin. 2003. Assessing the impact of the green revolution, 1960 to 2000. *Science* 300: 758–762.

________. 2007. Contributions of national agricultural research systems to crop productivity. In *Handbook of agricultural economics,* vol. 3, ed. R. Evenson and P. Pingali. New York: Elsevier.

Herren, H. R., and P. Neuenschwander. 1991. Biological control of cassava pests in Africa. *Annual Review of Entomology* 36: 257–283.

Herren, H. R., P. Neuenschwander, R. D. Hennessey, and R. D. Hammond. 1987. Introduction and dispersal of *Epidinocarisi lopezi* (Hym. Encytidae), an exotic parasitoid of cassava mealybug, *Phenococcus manihoti* (Hom. Pseudococcidae) in Africa. *Agriculture, Ecosystems, and Environments* 19: 131–144.

Herren, H. R. 1981. Biological control of the cassava mealybug. In *Tropical root crops research strategies for the 1980s*, ed. E. R. Terry, K. O. Oduro, and F. Caveness, Proceedings of the First Triennial Symposium of the International Society for Tropical Root Crops, September 8–12, 1980. Ottawa: International Development Research Center (IDRC).

Idowu, I. A. 1998. Private sector participation in agricultural research and technology transfer linkages: Lessons from cassava *gari* processing technology in southern Nigeria. In *Post-harvest technology and commodity* *marketing,* ed. R. S. B. Ferris, Proceedings of a Post-Harvest Conference, November 2 to December 1, 1995, Accra, Ghana. Ibadan, Nigeria: International Institute of Tropical Agriculture (IITA).

Jennings, D. L. 1976. Breeding for resistance to African cassava mosaic disease: Progress and prospects. In *African cassava mosaic*, ed. B. L. Nestel. Report of an interdisciplinary workshop held at Muguga, Kenya, February 19–22, 1976. Ottawa: IDRC.

Johnson, M. E., W. A. Masters, and P. V. Preckel. 2006. Diffusion and spillover of new technology: A heterogeneous-agent model for cassava in West Africa. *Agricultural Economics* 35 (2): 119–129.

Jones, W. O. 1959. *Manioc in Africa*. Stanford, Calif., U.S.A.: Stanford University Food Research Institute.

Korang-Amoakoh, S., R. A. Cudjoe, and E. Adams. 1987. Biological control of cassava in Ghana: Prospects for the integration of other strategies. In *Integrated pest management for tropical root and tuber crops,* ed. N. S. K. Hahn and F. E. Caveness. Ibadan, Nigeria: IITA.

Maredia, M. K., D. Byerlee, and P. Pee. 2000. Impacts of food crop improvement research: Evidence from Sub-Saharan Africa. *Food Policy* 25: 531–559.

Neuenschwander, P. 1996. Evaluating the efficacy of biological control of three exotic Homopteran pests in tropical Africa. *Entomophaga* 41: 405–424.

________. 2001. Biological control of the cassava mealybug in Africa: A review. *Biological Control* 21: 214–229.

________. 2004. Harnessing nature in Africa: Biological pest control can benefit the pocket, health, and the environment. *Nature* 432: 801–802.

Neuenschwander, P., W. N. O. Hammond, A. P. Gutierrez, A. R. Cudjoe, J. U. Baumgartner, and U. Regev. 1989. Impact assessment of the biological control of the cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae) by the introduced parasitoid *Epidinocarisis lopezi* (De Santis) (Hymenoptera: Encyrtidae). *Bulletin of Entomological Research* 79: 579–594.

Neuenschwander, P., and T. Haug. 1992. New technologies for rearing *Epidinocarsis lopezi* (Hym., Encyrtidae), a biological control agent against the cassava mealybug *Phenacoccus manihoti* (Horn., Pseudococcidae). In *Advances in insect rearing for research and pest management,* ed. T. E. Anderson and N. C. Leppla. Boulder, Colo., U.S.A.: Westview.

Nichols, R. F. W. 1947. Breeding cassava for virus resistance. *The East African Agricultural Journal* 12: 184–194.

Norgaard, R. B. 1988. The biological control of cassava mealybug in Africa. *American Journal of Agricultural Economics* 70 (2): 366–371.

Nweke, F. I. 2005. Collection and compilation of Nigeria's official crop statistics. Ibadan, Nigeria: IITA.

Nweke, F., and S. Haggblade. 2009. Africa's cassava surge. In *Successes in African agriculture: Lessons for the future,* ed. S. Haggblade and P. Hazell. Baltimore, Md., U.S.A.: Johns Hopkins University Press.

Nweke, F. I., D. S. C. Spencer, and J. K. Lynam. 2002. *The cassava transformation: Africa's best kept secret*. East Lansing: Michigan State University Press.

Ogbe, F. O., A. G. O. Dixon, J. d'A Hughes, F. Alabi, and R. U. Okechukwu. 2004. The status of cassava mosaic disease, cassava begomoviruses and whitefly vector population in Nigeria. Ibadan, Nigeria: IITA.

Onwueme, I. C., and T. D. Sinha. 1991. *Field crop production in tropical Africa*. Ede, the Netherlands: Technical Centre for Agricultural and Rural Cooperation (CTA).

Otim-Nape, G. W., and Anton Bua. 2000. Uganda case study: Cassava multiplication and distribution to needy farmers. Paper presented at the Global Cassava Development Strategy Validation Forum, April 26–28, 2000, FAO, Rome

Schulthess, F., J. U. Baumgartner, and H. R Herren. 1989. Sampling *Phenacoccus manihoti* in cassava fields in Nigeria. *Tropical Pest Management* 35: 193–200.

Ssemakula, G. N., Y. K. Baguma, G. W. Otim-Nape, A. Bua, and S. Ogwal. 1997. Breeding for resistance to mosaic disease in Uganda. *African Journal of Root and Tuber Crops* 2: 36–42.

Storey, H. H., and R. F. W. Nichols. 1938. Studies of the mosaic diseases of cassava. *The Annals of Applied Biology* 25 (4): 790–806.

Thresh, J. M., G. W. Otim-Nape, J. P. Legg, and D. Fargette. 1997. African cassava mosaic virus disease: The magnitude of the problem. *African Journal of Root and Tuber Crops* 2 (1–2): 13–19.

University of Greenwich. 2004. Uganda: Saving a nation besieged by cassava mosaic disease epidemic. Paper presented at the NEPAD/IGAD regional conference "Agricultural Successes in the Greater Horn of Africa," Nairobi, Kenya, November 22-25, 2004. Photocopy.

Wodageneh, A., and H. R. Herren. 1987. International cooperation: Training and initiation of national biological control programs. *Insect Science and Its Application* 8: 915–918.

World Bank. 2009. *Awakening Africa's sleeping giant: Prospects for commercial agriculture in the Guinea savannah zone and beyond.* Washington, D.C.: World Bank.

Yaninek, J. S. 1994. Cassava plant protection in Africa. In *Food crops for food security in Africa*, ed. M. O. Akoroda. Proceedings of the Fifth Triennial Symposium of the International Society for Tropical Root Crops—Africa Branch (ISTRC–AB). Ibadan, Nigeria: ISTRIC/CTA/IITA.

Zeddies, J., R. P. Schaab, P. Neuenschwander, and H. R. Herren. 2001. Economics of biological control of cassava mealybug in Africa. *Agricultural Economics* 24 (2): 209–219.

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